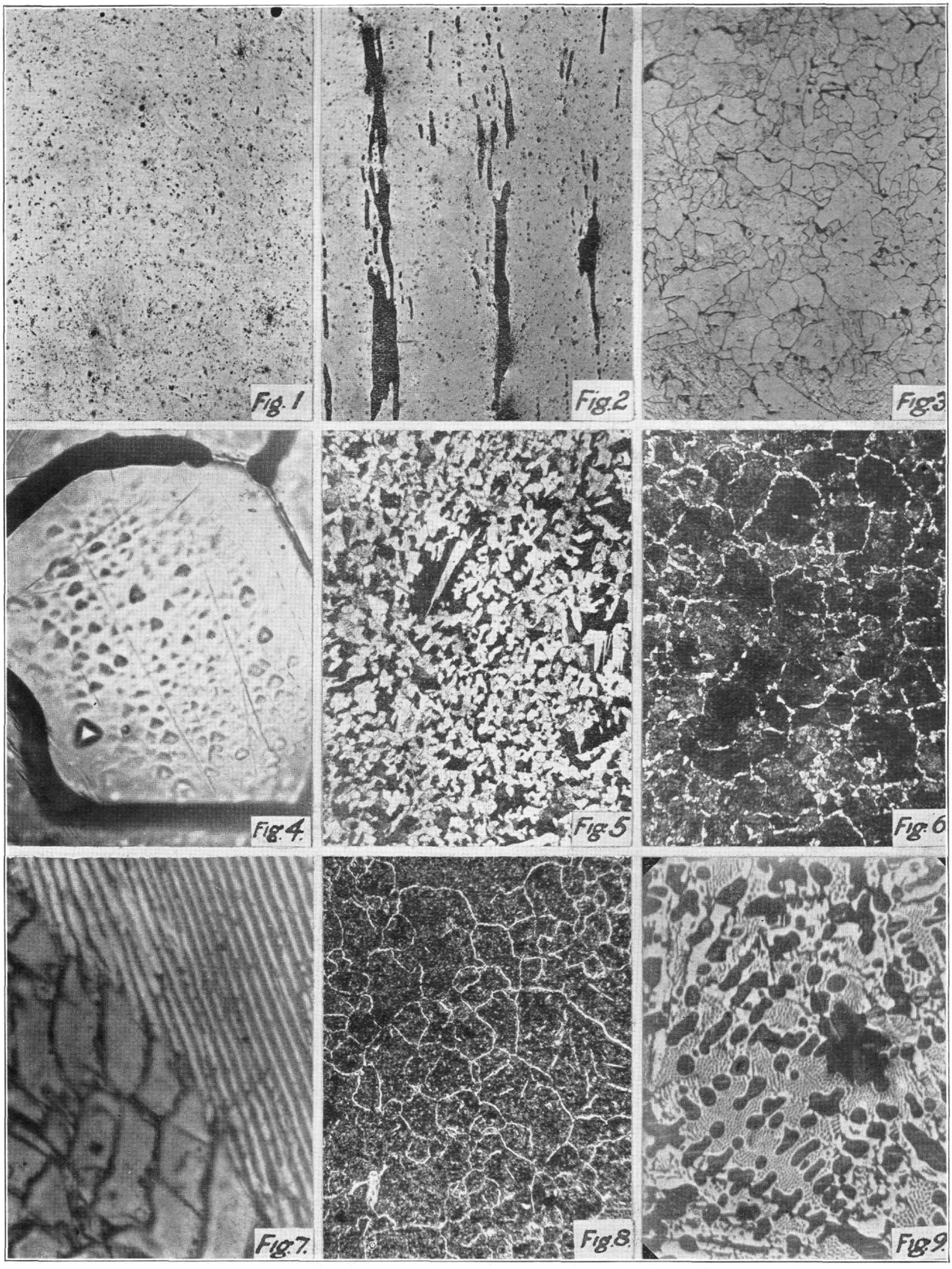

Figs. 1 and 2, (100 diameters) low carbon steel, polished but unetched. Fig. 3, same as Fig. 1 but etched in dilute acid. Fig. 4, pure nickel eached to show crystalline shape of pits. Figs. 5, 6 and 8 (100 diameters), carbon steels containing 35% C; 65% C., and 1.20% C. respectively. Fig. 7 "Pearlite" at high magnification (over 2000 diameters). Fig. 9, white cast iron (100 diameters).

The Effects of Carbon on Iron

Metallography and the Metallographic Microscope

By J. O. LORD

THE term Metallography has been defined in various ways the most general of which states that it is a study of the structure of metals. As originally conceived, structure referred to the arrangement and form of the various crystalline parts or phases of which the metal or metallic alloy was composed. These structures were revealed by the microscope or by a mere visual contemplation of the appropriately treated surface of the specimen, the latter method being termed *macroscopic*.

At present the definition should be extended to include the study of structures and their relations to the physical properties and characteristics of the metals; and the methods employed consist of every physical and chemical determination that can be performed, including measurements of thermal, electrical, and magnetic properties and the arrangement of atoms in the crystal space lattice as shown by the x-ray.

Metallography does not concern itself with those phases of metallurgy that deal with extraction of metals from their ores; with methods of shaping metals; or the manufacture of metallic articles except as such processes affect the structure of metal.

In our specialized engineering courses a great many of us miss some of the most interesting courses given in other departments of engineering. This non-technical article describing some of the processes used in metallography should be of particular interest to some of the Electricals, Architects, or Civils who do not have occasion to take any of the courses in the science described.—Editor.

Methods Used

In order to see the true structure of a piece of metal through the microscope, it is neccessary to have a surface that represents a true section such as would be caused by shearing or pulling the piece apart in tension. Such a surface is obtained in the following manner: First the piece is sawed with a hacksaw through some convenient part and in such a way as to produce a specimen of convenient size and shape. The sawed surface is now ground on the flat side of an emery wheel until no traces of the saw marks are left. Further grinding or rubbing on successively finer grades of emery produces a surface consisting of very fine scratches. Finally the surface is polished on a cloth covered wheel on which is poured a suspended mixture of some polishing powder such as jewelers rouge or levigated alumina powder. The last operation leaves the specimen with a mirror surface absolutely free from scratches. There will be no features of any kind on this surface except small rounded specks of non-metallic substance or holes in the metal. Figs. 1 and 2.

In order to show the structure of the metal the surface so that if the light is not reflected directly into the objective lens of the microscope the specsurface must now be treated chemically by a process known as etching. The simplest treatment is to immerse the piece in very weak or dilute acid. The acid dissolves certain parts faster than others thus producing relief. Other reagents are used which stain or color certain parts and not others.

The Microscope

The only difference between a metallographic microscope and any other kind is in the method used to illuminate the specimen. Whereas with most microscopes the light is passed through the article to be observed, in the case of metals this is impossible and the article must be viewed by reflected light. An added difficulty is caused by the fact that we are looking at practically a mirror imen will still look dark. This illumination is accomplished in several ways the simplest of which is the following:

In the microscope tube, just above the objective, a thin piece of glass is placed at an angle of 45 degrees to the vertical line of the microscope. A horizontal beam of light, directed onto the glass, through a hole in the side of the microscope tube is reflected downward through the objective which focuses it on the specimen. From the specimen it is reflected back into the microscope straight through the 45 degree glass and into the eye of the observer. With this method of illumination all parts of the specimen that are horizontal and smooth appear white but any portion that is at an angle or rough will appear dark or grey.

Microscopic Appearance of Carbon Steels

The accompanying micrographs of carbon steel will now be considered. Figure 1 shows the polished surface of a piece of steel unetched. The only features observable are small specks which are discontinuities in the metal due to small holes or to non-metallic inclusions such as oxides and sulphides. The holes appear larger than they actually are because, in polishing, a funnel shaped depression is formed about each hole and the sides of this depression, not reflecting light into the microscope, appear dark.

Figure 2 shows a piece of wrought iron, unetched. The long streaks of grey material are particles of slag which were trapped in the metal in the process of manufacture. The presence of these streaks is a characteristic of wrought iron by which it can always be identified.

Figure 3 is the micrograph of a piece of very low carbon steel which was used in making wire. Here the surface, which has been etched, as described above, appears to be broken into a larger number of fragments or grains. It is definitely

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CARBON ON IRON

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known that these grains are crystalline in structure, although not in outward form. Such a grain structure is characteristic of all pure metals and is caused by the fact that each crystal grows in all directions according to its crystal form and habit, until it meets its neighbor, which is also growing. The boundaries of separation between crystals will therefore be irregular since they are the result of chance location of the crystal nuclei. The material at the boundaries of the grains is always in a state of strain. This causes it to dissolve in the etching reagent more rapidly than the interior portion of the grain. Thus is the pattern produced which we see under the microscope, the grain boundaries appearing as narrow troughs around the grains.

When a crystal dissolves in acid, the rate of solution is not the same in all directions but depends on the positions of the crystal axes. This fact gave an early proof that these grains were really crystalline because it was found that, when deeply etched, certain pits or holes appeared which were not round but had flat sides corresponding to crystal faces. An example of this is shown in Fig. 4, a micrograph of pure nickel.

The presence of a second structural phase or constituent in metal is shown usually more easily than grain boundaries. There is often a marked difference in hardness that causes one feature to stand out above the others, even from the polishing; and the rate of solution in etching reagents is usually quite different. When carbon occurs in steel it appears as a second structural constituent with the formula Fe_3C known as cementite. This material is quite brittle and etches much less readily than iron. It forms a finely divided structure, however, with a certain portion of the iron, and this finely divided structure appears very dark under low magnifications. Figures 5 and 6, show this material in increasing amounts in steels containing .35% C. and .65% C. respectively. Fig. 7 shows the finely divided structure at high magnification (2750). Remembering that we are looking at a section of the material it is evident that the structure is produced by alternate plates of the two constituents. Material that is entirely composed of this structure contains about 0.9% C. or 13.5% cementite and is known as pearlite. When looked at in ordinary light it often shows iridescence like mother of pearl due to diffraction of light by the fine laminations.

In steels containing more than .9% C. (Fig. 8) the cementite appears as a network about the patches of pearlite and also as needles in the patches.

A certain correlation is observed between the microstructures and the physical strength of steel. Steels of very low carbon content have a tensile strength of from 30,000 to 40,000 lbs. per square inch and rather high ductility. Steels of pearlitic carbon content (viz. .9% C) will show a tensile strength of 120,000 lbs. per sq. in. or better, but are not so ductile, and the increase in strength of steels between .0% C. and .9% C. is just about proportional to the carbon present. Above .9% C. however the tensile strength does not increase materially but the material becomes more and more brittle. The above remarks only apply to annealed, slowly cooled steels. The profound effcets of rapid cooling on carbon steels will be considered in a later paper.

When an iron-carbon alloy is made containing two per cent of carbon or more the cementite takes on a different appearance from that at lower carbon content. Figure 9 shows the structure of a white cast iron containing about 3% carbon. The white portion is cementite and the dark portion, including the little black specks, is pearlite. As the carbon increases still more, we find the speckled structure increases in amount until at 4.3% carbon the specimen would consist entirely of the speckled structure. In cast irons containing more than 4.3% carbon the Fe_3C appears as long white crystals embedded in a matrix of speckled structure.

When cementite occurs in large masses it becomes very unstable at high temperatures, tending to decompose into iron and graphite. Hence it is quite difficult to make high carbon white cast iron by melting, and practically impossible to so make pure Fe_3C. Fe_3C has been obtained pure by dissolving the iron away from it in steel. When so prepared it is found to contain 6.67% C. as required by its formula.

Thus we see that this compound, Fe_3C, is responsible for most of the characteristics of cast iron and steel. Its presence can change the soft malleable element iron into a hard, tough, or rigid steel or into a brittle white cast iron.